DEVELOPMENT OF A NEW KENAF BAST FIBER-REINFORCED THERMOPLASTIC POLYURETHANE COMPOSITE

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A composite of themoplastic polyurethane (TPU) reinforced with short kenaf (*Hibiscus Cannabinus L.*) fiber (KF) was prepared by a melt-mixing method. Mixing was followed by compression molding to produce sheets for specimen cutting. Five samples were cut from the composite sheet. A mean value was taken for each sample according to ASTM standards. The aims of this study were to optimize the processing parameters and fiber size of TPU/KF composite. The method used to develop this composite consisted of two main steps. First, the influence of processing parameters such as temperature, time, and speed on tensile properties was studied. Second, effects of different fiber size on tensile properties, flexural properties, and impact strength were tested. The optimum blending parameters were 190°C, 11 min, and 40 rpm for temperature, time and speed, respectively. TPU/KF composites with different fiber sizes were prepared, namely, <125, 125-300, and 300-425 µm. Tensile and flexural strength and modulus were best for fiber size range between 125 and 300 µm. Impact strength showed a slight increasing trend with an increase in fiber size.

Keywords: Natural fiber composites; Thermoplastic polyurethane; Kenaf fibers

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INTRODUCTION

Natural fiber-reinforced polymers are attracting more notice due to benefits such as less abrasiveness to equipment, renewability, biodegradability, and reduction in weight and cost. Lack of compatibility is one of the problems facing natural fiber polymer composites. The hydrophobic nature of most polymers used in this field, versus the hydrophilicity of natural fibers, causes poor adhesion and wettability. Polyurethane is one of the hydrophilic polymers that would not face this kind of incompatibility (Özgür and Oksman 2008). No previous research has been done on natural fiber reinforced with TPU; however TPU has been compounded with synthetic fibers such as glass, aramid, and carbon fibers (Wilberforce and Hashemi 2009; Vajrasthira et al. 2003; Correa et al. 1998). TPU is more expensive than most polyolefins used in the field of natural fiber composites. Meanwhile, it has unique properties when compounded with natural fibers. One of the most important properties that can be found in the TPU when compounded to natural fibers - that is not found in polyolefins natural fiber composites - is the high strain. TPU-natural fiber composite can reach 35% strain without any treatment, while most polyolefins natural fiber composites cannot reach 10% strain. With some treatment TPU/KF reached 70% strain "mean value" in a study by the same authors (El-Shekeil et al. 2011).

Development of new composites using an internal mixer requires proper settings for parameters such as temperature, time, and speed in order to get the best results. Temperature is critical in processing; if it is low, it will lead to non-homogeneous distribution of fibers. In contrast, higher temperature might lead to thermal degradation for the fibers as well as the matrix.

Optimizing mixing time is also essential, since in a short mixing time homogeneous distribution might not take place. On the other hand, longer processing time causes thermal degradation of the matrix and breakage of polymer chains, due to shear stress and temperature.

Moreover, processing speed might lead to breakage of the fibers if high speed is applied. Low speed is inadequate to mix the compounds well. Fiber size (i.e., aspect ratio) used in composite materials significantly affects the mechanical properties of the composite (Lai et al. 2005).

The kenaf plant is an annual plant that can be harvested 2 to 3 times a year. It can grow to reach 3 to 4 meters within 4 to 5 months. The kenaf plant has three layers consisting of bast, core, and pith. Kenaf bast represents one third of the plant. Core and pith represent the rest. Kenaf bast fiber has been reported to have superior mechanical properties compared to the other parts of the plant (Aji et al. 2009). In this study, the main objective was to obtain optimized blending parameters and fiber size for TPU/KF composites.

EXPERIMENTAL

Materials

Polyester-based thermoplastic polyurethane (TPU) was obtained from Bayer Co. (Malaysia) Sdn Bhd, Petaling Jaya, Selangor, Malaysia. The specific gravity of the TPU was 1.21, the tensile strength was 48 MPa, the tensile modulus was 36 MPa, the melting temperature was 210°C, and the hardness was 55D. Kenaf V36 bast fiber was supplied from KEFI (Malaysia) Sdn Bhd, Setiu, Terengganu, Malaysia. Kenaf fibers and TPU used in this study are shown in Fig. 1.

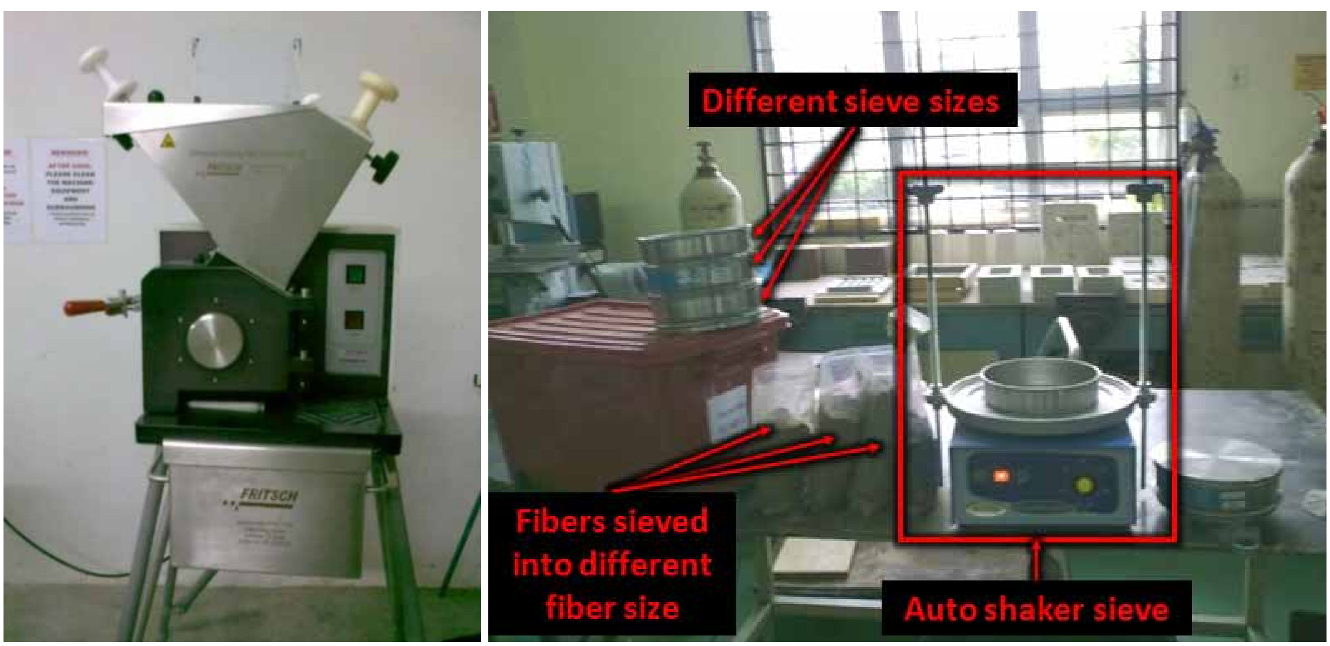
Preparation of Fiber

Bast fiber was extracted by mechanical decortication. Fiber was pulverized using a Fritsch Pulverisette mill. Figure 2 (a) shows the mill. Pulverized fiber was sieved using an auto shaker sieve into three different sizes (<125, 125-300, and 300-425 μm) using mesh 120, 50-120, and 40-50. The auto shaker sieve is shown in Fig. 2 (b).

Preparation of Composite

TPU/KF composite was compounded using a Haake Polydrive R600 internal mixer. The internal mixer is shown in Fig. 3(a). Matrix was charged into the mixer until torque was stabilized, and then fiber was added into the mixer. A 30% fiber loading was fixed throughout the study. The samples were prepared at different processing parameters, such as temperature, speed, and time.

Fig. 1. Kenaf fibers and TPU used in the study



(a) (b)

Fig. 2. (a) Mill used to pulverize the fibers, (b) Auto shaker sieve

The sample was hot pressed using Vechno Vation 40 ton compression moulding for 10 min at 190 °C. Prior to full-press, the sample was pre-heated for 7 min at 190°C. The sheet was then placed between two plates of a cold press to cool at 25 °C for 5 min. The compression moulding machine is shown in Fig. 3 (b).

(a) (b)

Fig. 3. (a) Internal mixer, (b) Compression molding machine

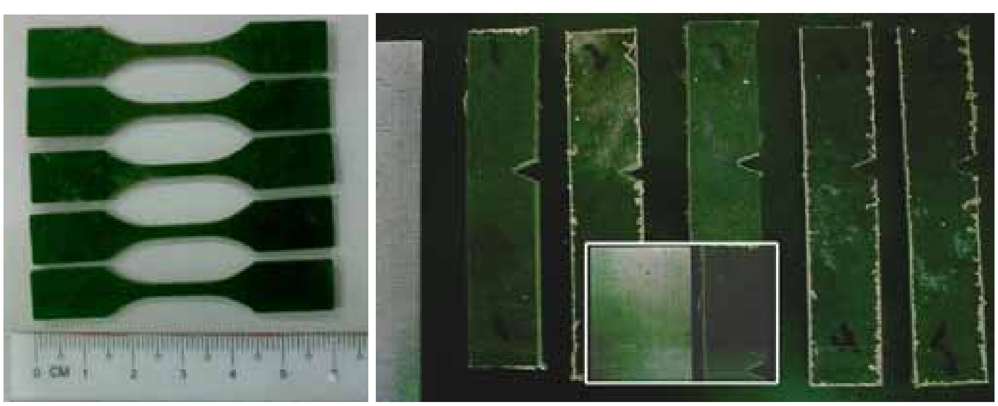
Characterization of Composite

Tensile testing

Tensile properties were measured using an Instron 3365 machine, according to ASTM D 638. The specimens were prepared by cutting them into dumbbell shapes using a hydraulic cutter machine. Five specimens were tested with a crosshead speed of 5 mm/min. Tensile specimens are shown in Fig. 4(a).

Flexural testing

Three-point bending flexural tests were conducted using an Instron 3365 machine, according to ASTM D 790. The specimens of 130 x 13 x 3 mm were cut using a band saw. Five specimens were tested with a crosshead-speed of 2 mm/min.



(a) (b)

Fig. 4. (a) Tensile specimens , (b) Impact specimens

Impact testing

Notched impact strength was measured with a 43-02-01 Monitor Impact Tester according to ASTM D 256. Dimensions of samples were 63 x 13 x 3mm. At least five samples were tested. The impact strength (kJ/m^2) was calculated by dividing the recorded absorbed impact energy by the cross-section area of the samples. Impact specimens are shown in Fig. 4 (b).

RESULTS AND DISCUSSION

Processing Parameters Optimization

Effect of processing temperature on tensile properties of TPU/KF composite

Figure 5 displays the effect of processing temperature on the tensile properties of TPU/KF composites. Three different temperatures were examined, 180, 190, and 200 °C. There are some reasons behind choosing these temperatures. In processing composite materials there should be consideration for the friction and shear forces that will occur during the mixing process; these operations will increase the temperature significantly. If the setting temperature for example is 180 °C, it can noticed that the real mixing temperature is around 210 °C (look at Fig. 6). In this study the aim was to produce a homogenous mixing without reaching the critical high temperatures that might start degrading natural fibers; such degradation would consequently affect the properties of the composite. This is the reason behind using the range between 180 and 200 °C to process the composite.

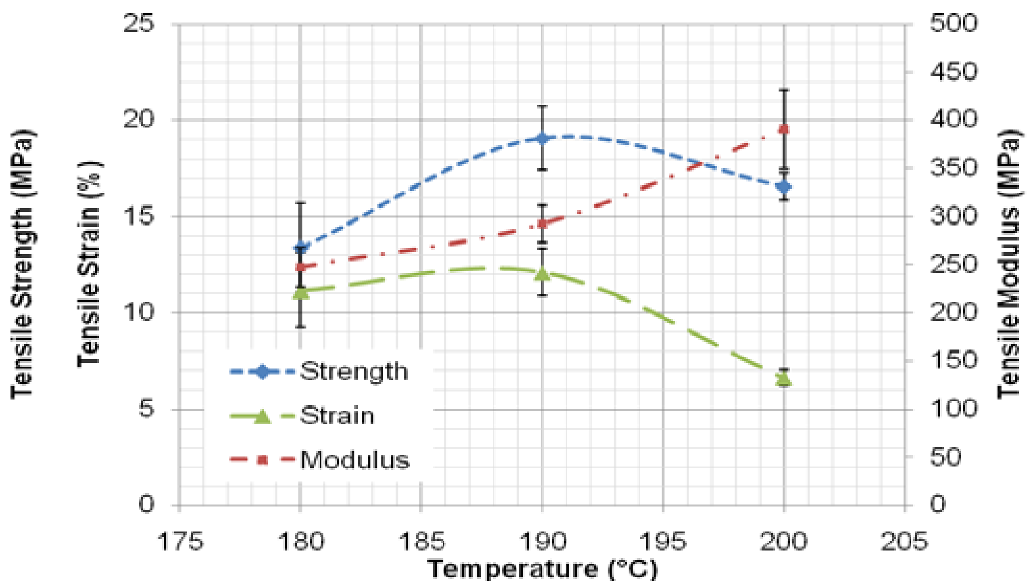


Fig. 5. Effect of processing temperature on tensile properties of TPU/KF composite

Temperatures less than 180 °C are much less than the melting temperature of the matrix, which will result in non-homogeneous mixing. Moreover, temperatures more than 200 °C will be critical for natural fibers; thermal degradation might start affecting mechanical properties of the natural fibers (Bogoeva-Gaceva et al. 2007). The rotor speed and time were fixed at 50 rpm and 15 min, respectively.

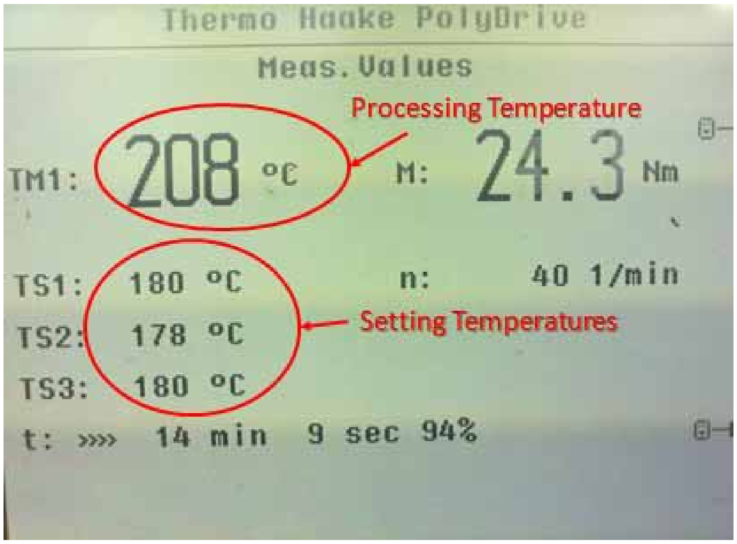


Fig. 6. Difference between setting temperatures and processing temperature

It can be seen from Fig. 5 that strength increased from 13.4 MPa at 180 °C to reach ca. 19.1 MPa at 190 °C and decreased to ca. 16.5 MPa at 200 °C. Low strength at 180 °C is attributed to a higher viscosity of the matrix, which causes non-homogeneous distribution (i. e. poor disper-sion) of the fibers during processing. With poor dispersion, fibers will not effectively participate in stress transfer. The decrease of strength at 200 °C might be attributed to thermal degradation of the natural fibers in the composite. Strain also increased slightly from 11% at 180°C to 12% at 190, and then decreased to 6.6% at 200°C. Modulus showed an increasing trend with an increase of mixing temperature. The highest strength at 190°C indicates a better interfacial bonding. Thus, 190°C is considered as the optimum mixing temperature.

Effect of processing time on tensile properties of TPU/KF composite

Figure 7 demonstrates the effect of processing time on the tensile properties of TPU/KF composites. Three different times were examined; 11, 13, and 15 min. The temperature and rotor speed were fixed at 190°C and 50 rpm, respectively. Choosing these processing times was based on observation of the torque in the mixer. Torque gives a precise image of the condition of compounds inside the mixer. If torque is not stabilized, this indicates that blending has not been sufficiently mixed, which will lead to poor dispersion. In contrast, if the compounds are kept mixing for long time after stabilization of the torque, this may lead to thermal degradation and breakage of matrix chains. Fibers also will break due to shear stress and temperature. Thus, the overall performance of the composite will be affected (Lai et al. 2005). By looking at Fig. 7, it can be noticed that strength was decreased significantly with increasing mixing time. The strength of 23.6, 21.5, and 19 MPa was noticed for 11, 13, and 15 min, respectively. Strain has shown the same trend of strength. Modulus didn't show a significant change with increasing mixing time. As mentioned in the previous section, a better strength shows a better interfacial bonding, so 11 minutes gave the highest tensile strength of 23.6 MPa and was judged to be the optimum time for mixing.

Effect of processing speed on tensile properties of TPU/KF composite

Figure 8 shows the effect of rotating speed on the tensile properties of TPU/KF composite. Three different speeds were examined; 30, 40, and 50 rpm. The temperature and time were fixed at 190 °C and 11 min, respectively, as optimized in the previous steps.

It can be seen from Fig. 8 that strength increased from ca. 30.3 MPa at 30 rpm to reach ca. 33.5 MPa at 40 rpm and decreased to ca. 23.6 MPa at 50 rpm. Reduction of strength with increasing the speed is most probably due to the friction and breakage of the fibers. On the other hand, at lower speeds the materials were not mixed well (i. e. not homogeneous). Strain also increased from 25.9% at 30 rpm to 32.6% at 40 rpm, and then decreased to 20% at 50 rpm. Modulus did not show a significant change with different mixing speed. The optimum mixing speed is 40 rpm with strength of 33.5 MPa.

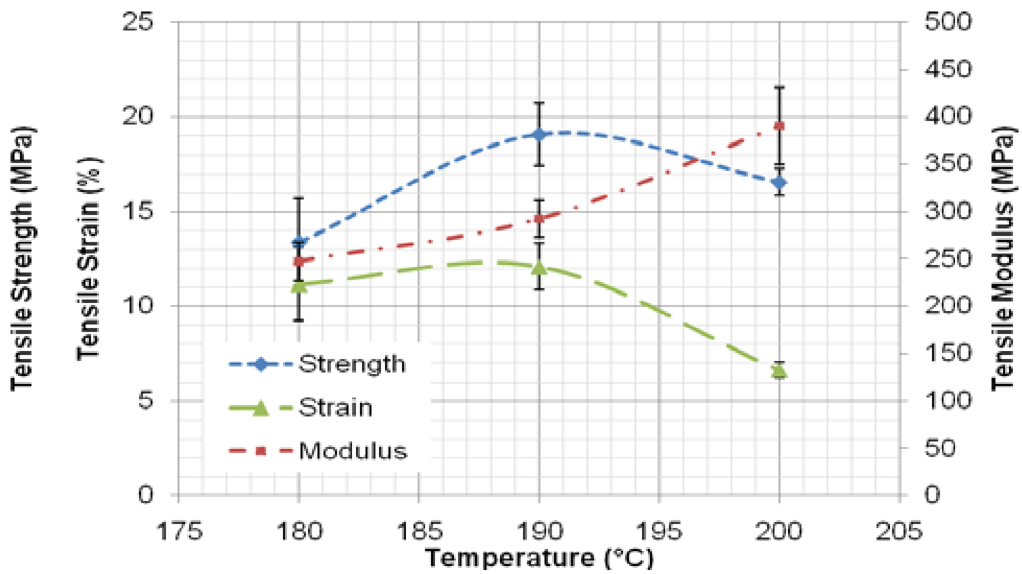


Fig. 6. Effect of processing temperature on tensile properties of TPU/KF composite

Fiber Size Optimization

Effect of fiber size on tensile properties of TPU/KF composite

Figure 9 shows the effect of fiber size on the tensile strength of TPU/KF composite. Three different sizes were examined <125, 125-300, and 300-425 µm. The temperature, time, and speed were fixed at 190 °C, 11 min, and 40 rpm, respectively. Strength increased from 24.2 MPa at the smallest fibers to 33.5 MPa at the medium size fibers, and then decreased to 30 MPa for fibers between 300 and 425 µm. Strain showed an increasing trend with increasing fiber size. Modulus showed the same trend as strength. It increased to a peak of 265 MPa then decreased with increasing fiber size. The highest strength with fiber size between 125 and 300 µm implies better interfacial bonding and wettability. The reason behind low strength of small fiber size is probably because smaller size fiber possessed larger surface area, leaving more surfaces nonreactive to the matrix. Thus, more stress points were created, resulting in reduced tensile strength (Rozman et al. 2001). Lower strength for fibers between 300 and 425 µm is attributed to poorer dispersion and agglomeration. A similar trend has been found by Sobhy and Tammam (2010) when they studied three different fiber size (i. e. <125, 125-

250, and 250-500 µm) of wheat husk fibers reinforced rubber composites.

It can be noted that the best tensile strength of the composites after optimizing processing parameters, and after optimizing fiber size was 33.5 MPa, which is much lower than the neat TPU which has tensile strength of 48 MPa. In order to understand the reason behind this significant reduction in tensile strength, neat TPU was processed using the same processes that the composites underwent (i.e. mixing using internal mixer followed by hot pressing using compression moulding). After processing, TPU was tensile tested. It showed tensile strength of 32.8 MPa. This significant reduction in tensile strength in the composite and neat TPU is most probably attributed to the breakage of the polymer chains caused by shear in the internal mixer.

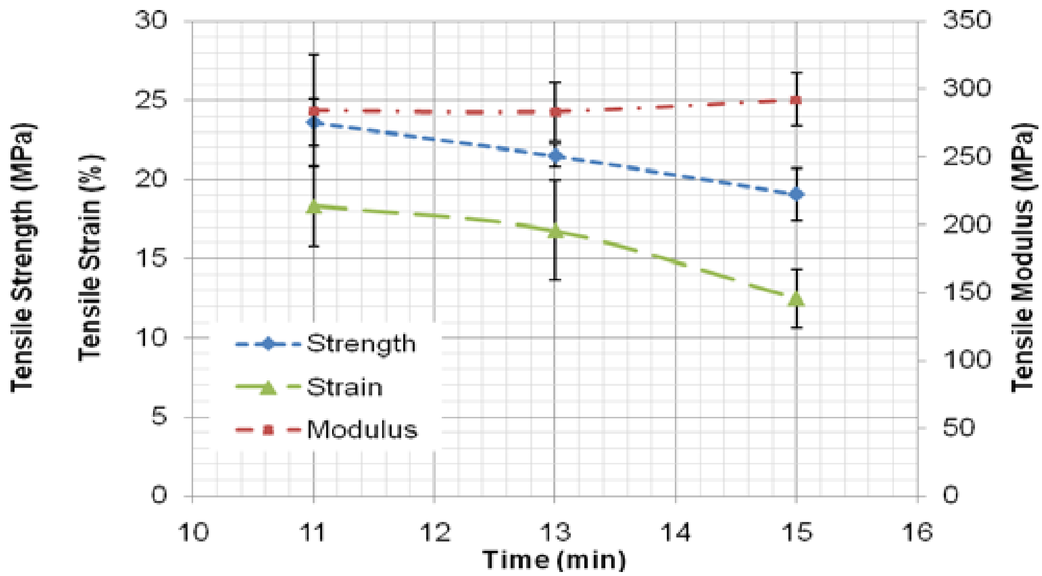


Fig. 7. Effect of processing time on tensile properties of TPU/KF composite

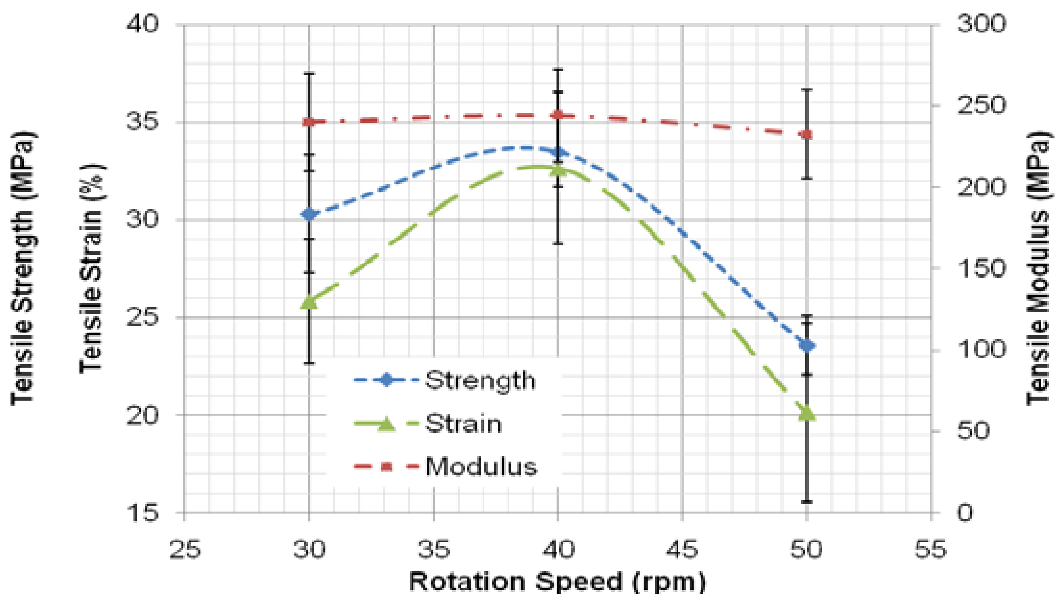


Fig. 8. Effect of processing speed on tensile strength of TPU/KF composite

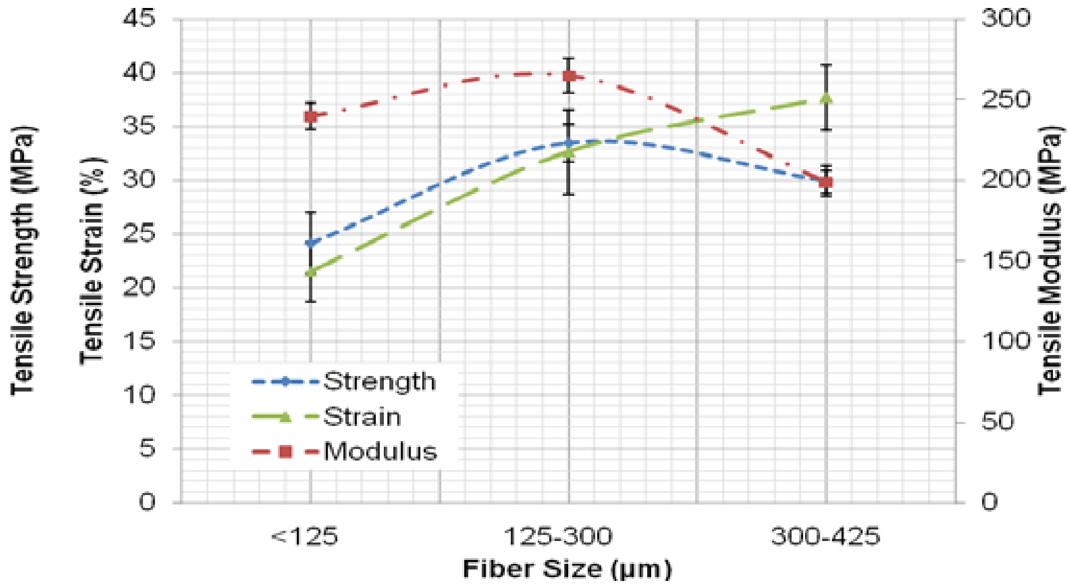


Fig. 9. Effect of fiber size on tensile strength of TPU/KF composite

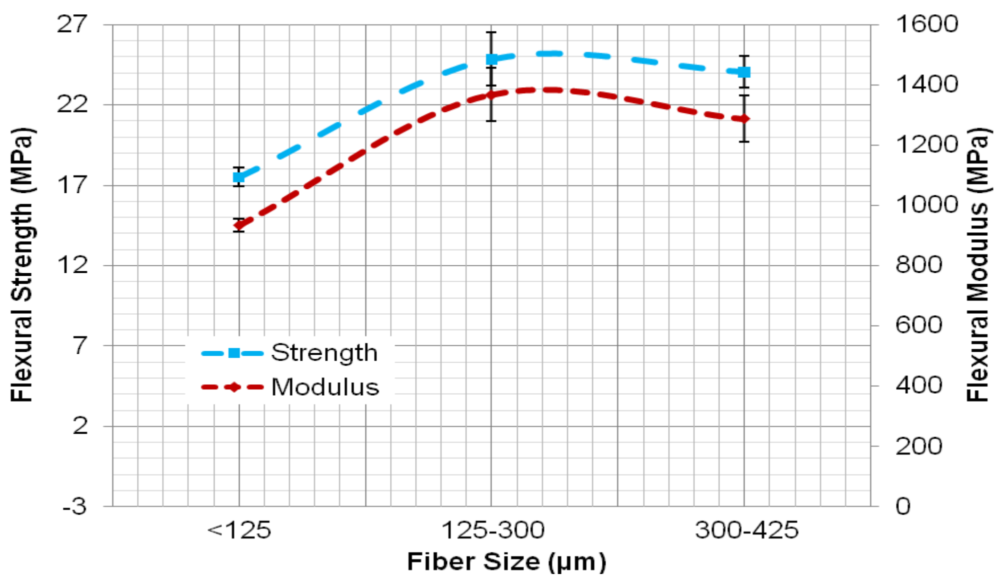


Fig. 10. Effect of fiber size on flexural properties of TPU/KF composite

Effect of fiber size on flexural properties of TPU/KF composite

Figure 10 indicates the effect of fiber size on the flexural strength of TPU/KF composite. A significant increase of flexural strength was observed from 17.5 MPa with the smallest fibers to 24.8 MPa with the medium size fibers, and then slightly decreasing to 24 MPa with fibers between 300 and 425 µm. Flexural modulus showed the same trend with increasing fiber size. It increased from 934 MPa to 1366 MPa, and then decreased to 1287 MPa flexural strength. Modulus showed the same trend as the tensile strength.

Effect of fiber size on impact strength of TPU/KF composite

Figure 11 shows the effect of fiber size on the impact strength of TPU/KF composite. It can be seen that increasing fiber size resulted in an increasing trend of the impact strength. There was a significant increase from 2.1 kJ/m^2 at the smallest fiber size to 2.76 kJ/m^2 at the medium fiber size. This was followed by a slight increase to 2.97 kJ/m^2 at the fiber size between 300 and 425 µm.

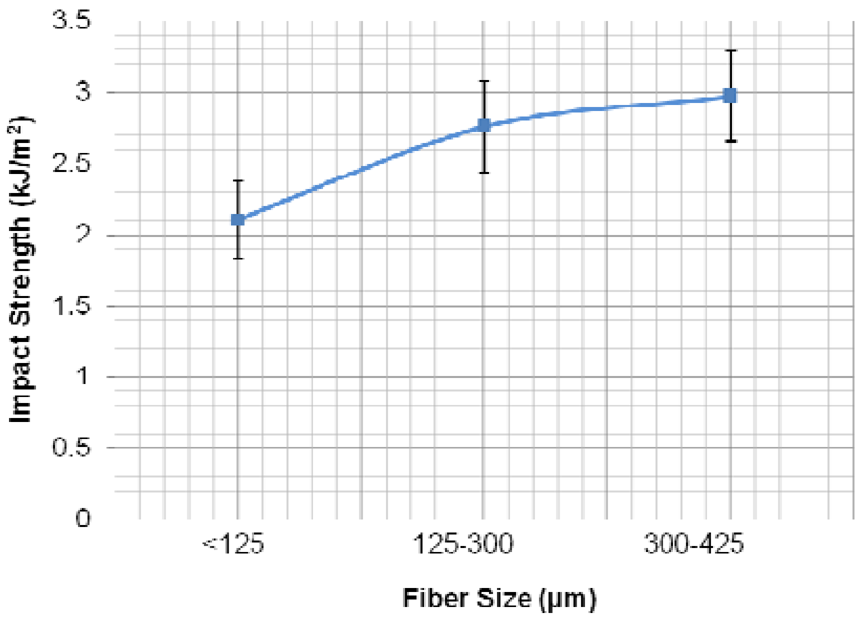


Fig. 11. Effect of fiber size on impact strength of TPU/KF composite

Fibers between 300 and 425 µm resulted in only 7% increment in impact strength. This means that larger fiber size contributed more to the absorption of energy. From the result of tensile, flexural properties, and impact strength fiber size between 120 and 300 µm can be considered as the optimum fiber size for TPU/KF composites. It resulted in the highest tensile and flexural strength and modulus, and a slightly less impact strength than fiber size between 300 and 425 µm.

CONCLUSIONS

The development of a new TPU/KF composite was successful. Changing various processing parameters (i.e. temperature, time, and speed) showed significant changes in the tensile properties. Optimum values 190 °C, 11 min, and 40 rpm, of temperature, time and speed, respectively, were chosen based on the best tensile strength of 33.5 MPa. Different fiber size showed significant influence on the tensile and flexural properties and impact strength. Fiber sizes in the range between 125 and 300 µm exhibited the best tensile and flexural strength and modulus. A larger fiber size showed only a slight increment of impact strength of about 7%. Therefore, a fiber size between 125 and 300 µm was considered to be the optimum size amongst the three size ranges examined.

ACKNOWLEDGMENTS

Parts of this paper have been presented in the Eighth International Conference of Composite Science and Technology ICCST8, Kuala Lumpur, Malaysia, March 2011. Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education Malaysia grant number (01-10-10-924FR) is acknowledged for support of this study. The authors wish to thank Bayer Co. (Malaysia) Sdn Bhd, Petaling Jaya, Selangor, Malaysia for the TPU supply and the information provided.

REFERENCES CITED

Aji, I. S., Sapuan, S. M., Zainudin, E. S., and Abdan, K. (2009). "Kenaf fibres as reinforcement for polymeric composites: A review," *International Journal of Mechanical and Materials Engineering* 4(3), 239-248.

Bogoeva-Gaceva, G., Avella, M., Malinconico, M., Buzarovska, A., Grozdanov, A., Gentile, G., and Errico, M. E. (2007). "Natural fiber eco-composites," *Polymer Composites* 28(1), 98-107.

Correa, R. A., Nunes, R. C. R., and Filho, W. Z. F. (1998). "Short fiber reinforced thermoplastic polyurethane elastomer composites," *Polymer Composites* 19(2), 152-155.

Lai, C. Y., Sapuan, S. M., Ahmad, M., Yahya, N., and Dahlan, K. (2005). "Mechanical and electrical properties of coconut coir fiber-reinforced polypropylene composites," *Polymer-Plastics Technology and Engineering* 44(4), 619-632.

Özgür Seydibeyoğlu, M., and Oksman, K. (2008). "Novel nanocomposites based on polyurethane and micro fibrillated cellulose," *Composites Science and Technology* 68(3-4), 908-914.

Rozman, H. D., Tay, G. S., Abubakar, A., and Kumar, R. N. (2001). "Tensile properties of oil palm empty fruit bunch–polyurethane composites," *European Polymer Journal* 37(9), 1759-1765.

Sobhy, M. S., and Tammam, M. T. (2010). The influence of fiber length and concentration on the physical properties of wheat husk fibers rubber composites," *International Journal of Polymer Science* Vol. 2010, Article ID 528173, 8 pp.

Vajrasthira, C., Amornsakchai, T., and Bualek-Limcharoen, S. (2003). "Fiber-matrix interactions in aramid-short-fiber-reinforced thermoplastic polyurethane composites," *Journal of Applied Polymer Science* 87(7), 1059-1067.

Wilberforce, S., and Hashemi, S. (2009). "Effect of fibre concentration, strain rate and weldline on mechanical properties of injection-moulded short glass fibre reinforced thermoplastic polyurethane," *Journal of Materials Science* 44(5), 1333-1343.

Y. A. El-Shekeil, S. M. Sapuan, K. Abdan, and E.S. Zainudin. Proceedings of 2011 International Conference on Advanced Materials Engineering (ICAME 2011), Cairo, Egypt, 1-3 October, 2011.

Article submitted: July 16, 2011; Peer review completed: September 14, 2011; Revised version received: September 19, 2011; Accepted: September 24, 2011; Published: September 27, 2011.